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Indirect Drive Cold-Loaded Ignition Target Design

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September 7, 2004

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Indirect Drive Cold-Loaded Ignition Target Design

This document summarizes the Indirect Drive Cold-Loaded (diffusion-filled) Ignition Target design. These targets include a capsule whose strength is insufficient to withstand the room temperature pressure of the DT fuel. These capsules are diffusion filled with DT gas and then cooled to cryogenic temperature. The target must remain at cryogenic temperature until it is shot. Only features that affect the design of the NIF Cryogenic Target System (NCTS) are presented. The design presented is the current thinking and may evolve further. The NCTS should be designed to accommodate a range of targets and target scales, as described here.

The interface location between the target and the NCTS cryostat is at the target base / gripper joint.

Target Geometry

Overall: The overall Indirect Drive Cold-Loaded Ignition Target design is shown in Figure 1.
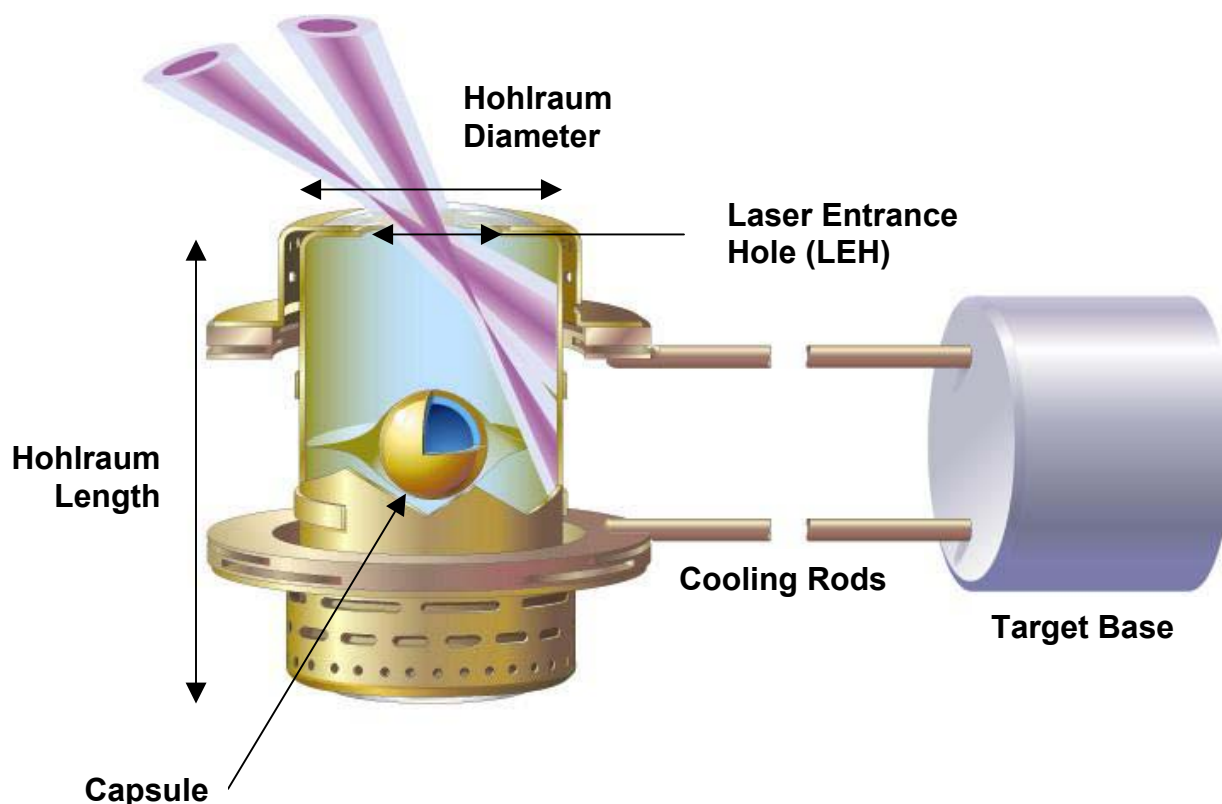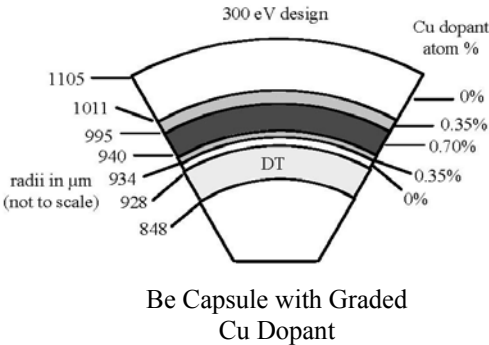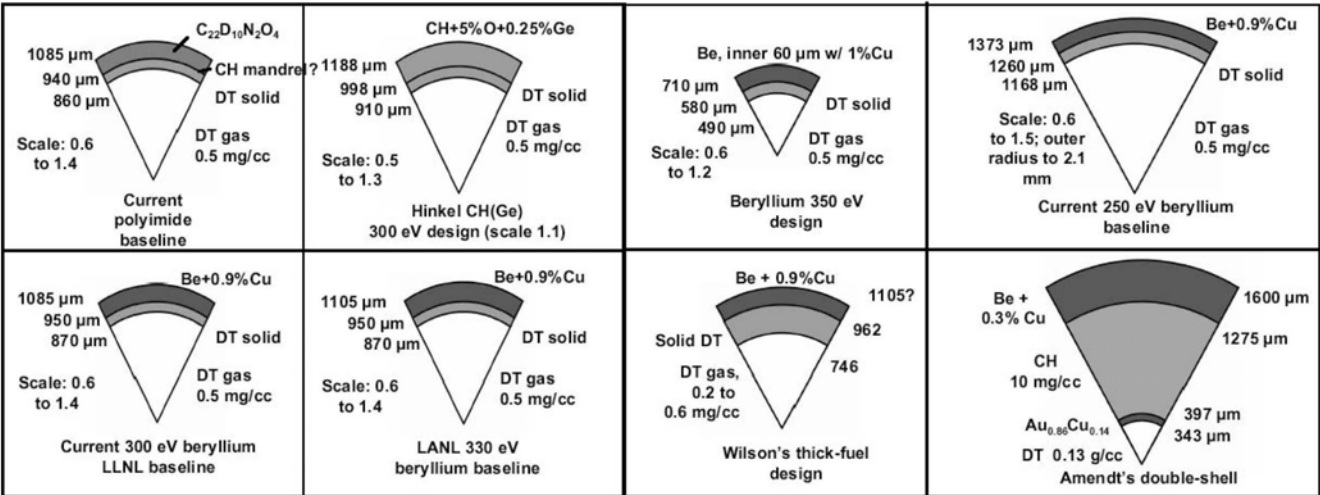

Figure 1. Indirect Drive Cold-Loaded Ignition Target

The lowest bending mode of the overall target assembly at "Scale 1" is TBD. The maximum allowable impact load to the overall target assembly is TBD.

Capsule: Many different capsule designs and materials, including CH, polyimide, and beryllium, are being considered for indirect drive ignition targets.[1,2,3], as shown in Figure 2 and Table 1. The CH and polyimide capsules are diffusion filled through the capsule wall. The beryllium capsules are diffusion filled through a hole in the capsule wall that is covered by the support tent, as shown in Figure 3. Note that the geometries given are for "Scale 1" designs. The figure shows a range on the cold-loaded targets from as small as "Scale 0.5" to as large as "Scale 1.4". However target designers have asked that targets as large as a hohlraum length of 25mm (Scale 2.63) be accomodated.[8]

The composition of the DT fuel shall be:
Tritium Concentration:	(47-53%) measured to <2%
Protium Concentration:	(<1%) measured to ~0.3%
He^3 Density:	(<0.1 mg/cc within 0.025 mg/cc of nominal) measured to 0.01 mg/cc
Other Species:	(<0.002%) measured to 0.002%

Figure 2. Scale 1 NIF Indirect Drive Cold-Loaded Ignition Capsule Designs (References 1, 2 and 3)

TABLE 1. Geometry, Curies, Fill Pressures, and DT Gas Density and Temperature for Indirect Drive Cold-Loaded Targets

Design	Scale	Hohl-raum Dia.	Hohl-raum Length	Capsule Outer Radius	DT Ice Outer Radius	DT Ice Inner Radius	Aspect Ratio	# of Curies (Ref 9)	DT Fill Pressure @ 300K (Ref 10)	DT Fill Pressure @ 300K (Ref 10)	DT Gas Density At Shot	DT Gas Temp At Shot
		(mm)	(mm)	(μm)	(μm)	(μm)		(Cu)	(Mpa)	(psia)	(mg/cc)	(K)
Current Polyimide Baseline	0.6	3.3	5.7	651	564	516	.085	0.258	35.96	5216	0.5	19.3
	1.0	5.5	9.5	1085	940	860	"	1.192	"	"	"	"
	1.4	7.7	13.3	1519	1316	1204	"	3.272	"	"	"	"
Hinkel CH (Ge) 300eV	0.5	2.8	4.8	499	598.8	455	.088	0.184	37.31	5411	0.5	19.3
	1.0	5.5	9.5	1188	998	910	"	1.474	"	"	"	"
	1.3	7.2	12.4	1544	1297	1183	"	3.238	"	"	"	"
Beryllium 350eV Design	0.6	3.3	5.7	426	348	294	.155	0.103	71.65	10,390	0.5	19.3
	1.0	5.5	9.5	710	580	490	"	0.475	"	"	"	"
	1.2	6.6	11.4	852	696	588	"	0.821	"	"	"	"
Current 250eV Beryllium Baseline	0.6	3.3	5.7	824	756	701	.073	0.539	30.35	4402	0.5	19.3
	1.0	5.5	9.5	1373	1260	1168	"	2.494	"	"	"	"
	1.5	8.3	14.3	2060	1890	1752	"	8.419	"	"	"	"
Current 300eV Beryllium LLNL Baseline	0.6	3.3	5.7	651	570	522	.084	0.263	35.56	5158	0.5	19.3
	1.0	5.5	9.5	1085	950	870	"	1.219	"	"	"	"
	1.4	7.7	13.3	1519	1330	1218	"	3.345	"	"	"	"
LANL 330eV Beryllium Baseline	0.6	3.3	5.7	663	570	522	.084	0.263	35.56	5158	0.5	19.3
	1.0	5.5	9.5	1105	950	870	"	1.219	"	"	"	"
	1.4	7.7	13.3	1547	1330	1218	"	3.345	"	"	"	"
Wilson's Thick-Fuel Design	1.0	5.5	9.5	1105	962	746	.225	2.939	117.8	17,080	0.2	17.5
	1.0	5.5	9.5	1105	962	746	"	2.907	115.5	16,750	0.6	19.6
Amendt's Double-Shell	1.0	5.5	9.5	1600	343	N/A	N/A	0.126	107.9	15,650	1300	300
300eV Be Capsule with Graded Cu Dopant	0.6	3.3	5.7	663	557	509	.086	.2509	36.44	5285	0.5	19.3
	1.0	5.5	9.5	1105	928	848	"	1.161	"	"	"	"
	1.4	7.7	13.3	1547	1299	1187	"	3.184	"	"	"	"
Haan's Upper Limit[8]	2.63	14.5	**25.0**	2908	2442	2232	"	21.10	"	"	"	"

The average DT solid layer thickness shall be within 0.5 micron of specified and measured to an accuracy of 0.25 micron.[4] The required room temperature diffusion fill pressures can be calculated from the DT solid layer thickness. The capsules shown in Figure 2 and Table 1 require fill pressures up to about 118 MPa (17,000 psia) (1160 atm) at room temperature (300 K). The system to permeation fill the capsules should, however, be designed for considerably higher pressures to allow for capsule design evolution.
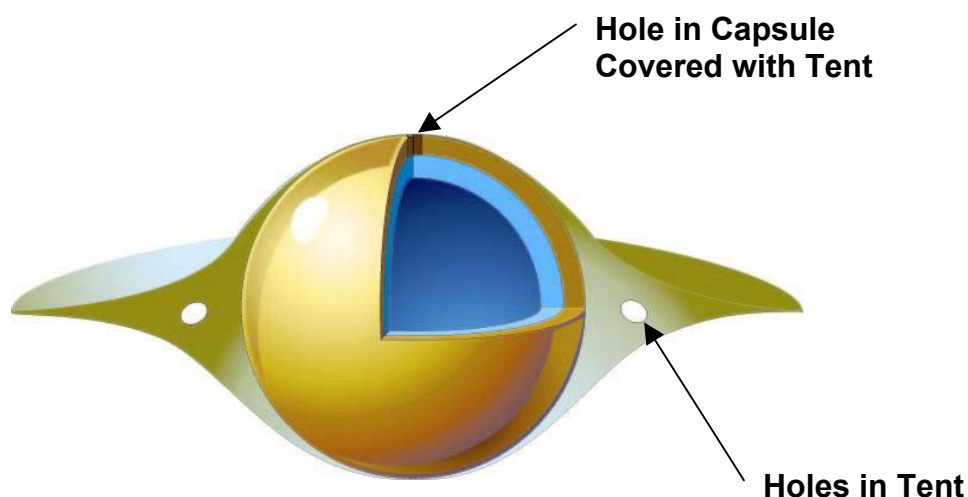
**Hole in Capsule
Covered with Tent**

Holes in Tent

Figure 3. Proposed Method to Diffusion Fill a Beryllium Capsule

The DT gas density at shot time shall be controlled to <0.01mg/cc, which corresponds to a temperature of <~50mK. The required temperature of the capsule is set by the DT vapor density, as shown in Figure 4.[7] For example, 0.5 mg/cc corresponds to ~19.3 K. Target performance is improved as gas density is decreased, with better performance at 0.3 mg/cc and optimum performance at 0.1 mg/cc. Layering experiments, however, have shown that the DT ice inner surface roughens as the gas density (temperature) is decreased. The NCTS design should provide operation at a range of gas densities (temperatures) between 0.1 mg/cc and the DT triple point to allow optimization of target performance.
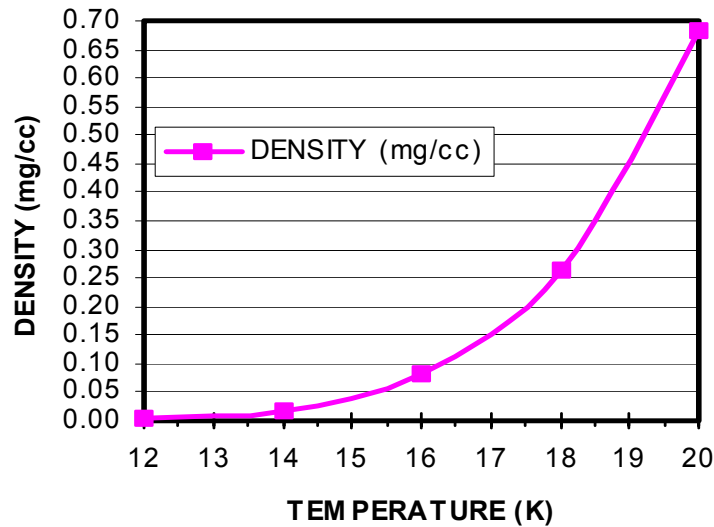
Figure 4. DT Saturated Vapor Density

Hohlraum: The hohlraum is a gold cylinder with a 5.5 mm diameter and a 9.5 mm length with a wall thickness of 100 micron (Scale 1)[2], however, other materials (e.g. cocktail hohlraums) and wall thicknesses are possible. The hohlraum scale will vary directly with the capsule scale. The laser entrance hole (LEH) at the end of each hohlraum is ~3.0 mm in diameter and will, however, not change with scale. Hohlraum temperature equalizing rings, which are designed to equalize the radial temperature distribution around the hohlraum, are connected to the top and bottom of the hohlraum. The temperature stability of the equalizing rings shall be +/- 1mK or better.[5]

The distance from the hohlraum centerline to the target base / gripper interface plane is TBD.

During layering, the hohlraum will be filled with He gas at a pressure of 10 to 50 mtorr. This gas is used to provide a thermal conduction path between the capsule and the hohlraum wall. At shot time, the hohlraum will be filled with He or H_2 + He tamping gas at a nominal density of between 1.25 mg/cc. The density of the tamping gas ranges from 0.75 and 1.5 mg/cc.[3] The density shall be measured to +/- 10%.[4] The required time to fill the hohlraum with tamping gas is TBD. The composition of the gas shall be measured to 10% for all atomic fractions.[4]

The tamping gas is filled through a TBD diameter fill tube. The tamping gas fill tube extends from the target base to the hohlraum.

Cooling Rods: The cooling rods connect the hohlraum to the target base. Figure 1 shows two cooling rods, but designs with four rods have been proposed. Designs with truss-like (radio tower) cooling rods have also been proposed. The rods will be either sapphire or high-purity aluminum. The rods will have a diameter of approximately 0.5 mm and a length of TBD mm.

Target Base: The target base connects the target assembly to the NCTS Target Inserter and Cryostat (TIC). Figure 5 shows an example of an early target base design (D2TS). The figure shows the face of the target base that directly connects to the TIC.

The target base shall include blast shield material. This auxiliary blast shield shall intercept shot products which come through holes in the main blast shield. The holes in the main blast shield are to allow for penetration of the cooling rods, fill tube(s), and electrical wires.

The interfaces between the target base and the NCTS gripper are:

  · Electrical interface: TBD (# of wires and gage for temperature sensors and heaters)
  · Gas interface: TBD (tamping gas)
  · Alignment interface: TBD (holes and/or slots for alignment pins)
  · Mechanical interface: TBD (collar for NCTS gripper to hold the target base)
  · Thermal interface:
        - Heat Load at Temperature: 200 mW at 7 K.[5]
        - Temperature stability of interface: +/- 10 mK
        - Temperature ramp-rate of interface: Variable between 0.5 and 10 mK/min.

Figure 5. Example of a Target Base Design

Characterization and Layering

The DT ice layer inside the capsule shall be characterized from two orthogonal directions. One characterization axis is vertical through the laser entrance hole windows.

The other characterization axis is transverse – orthogonal to both the hohlraum axis and the target positioner axis. The sides of each hohlraum will have slots to allow for characterization in this

transverse axis. These slots will be arranged in a "star-burst" pattern as shown in Figure 6.[6] The NCTS must provide a suitable characterization capability for these two orthogonal views.

The characterization methods used will be shadowgraphy and phase contrast x-ray. The time required to characterize a target using shadowgraphy is TBD. During this shadowgraphy characterization period, the maximum capsule motion must be less than TBD microns.

The time required to characterize a target using phase contrast x-ray is TBD. During this phase contrast x-ray characterization period, the maximum capsule motion must be less than TBD microns.

Layering of the DT ice shall be done by natural beta layer and infrared (IR) layering. The maximum power required for IR layering is TBD Q_{DT}. The IR light shall enter the hohlraum through TBD [either through the hohlraum wall or through the LEHs].

Figure 6. Star-burst Characterization Slots.

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